ISBN: 978-3-95450-202-8 doi:10.18429/JACoW-HB2018-THP1WB01

COMMISSIONING STATUS OF LINEAR IFMIF PROTOTYPE ACCELERATOR (LIPAc)

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Abstract

Significant progress was obtained on the installation and commissioning of the Linear IFMIF Prototype Accelerator (LIPAc). On the injector experiment, the emittance of 0.2 πmm·mrad has been demonstrated, which is well smaller than that of required value (0.3 πmm·mrad). Eight sets of RF modules (175 MHz, 200 kW for each) were connected to the RFQ with 8 coaxial waveguides, and RF conditioning has been started. With a simultaneous power injection from 8 RF modules into the RFQ and careful conditioning, a required RF filed for the 5 MeV D+ beam acceleration was obtained at short pulse. The pulse extension is underway toward the CW operation. The first H+ beam acceleration will be started in June 2018. After the H+ beam commissioning, D+ beam acceleration will be implemented aiming at 5 MeV 125 mA, 0.1% duty. In parallel, the preparation of SRF (superconducting Radio-Frequency linac), which accelerates the D+ beam up to 9 MeV, has proceeded.

INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) aims to provide an accelerator-based, D-Li neutron source to produce high energy neutrons at sufficient intensity and irradiation volume for DEMO reactor materials qualification. The IFMIF/EVEDA project, which is part of the Broader Approach (BA) agreement between Japan and EU, has the mission to work on the engineering design of IFMIF and to validate the main technological challenges [1, 2]. The LIPAc being developed in the IFMIF/EVEDA project has the objective to demonstrate 125 mA/CW deuterium ion beam acceleration up to 9 MeV and is composed of 10 major systems as shown in Figure 1. Especially, important main accelerator parts are an injector, a Radio Frequency Quadrupole Linac (RFQ) accelerator, and a first part of superconducting RF (SRF) Linac.

The LIPAc is under validation. The first accelerator component which allows the production of a 140 mA-100 deuteron beam has been already demonstrated the commissioning at Rokkasho showing promising performance. The validation of the second phase (100 keV to 5 MeV), so called RFQ acceleration phase, has been just started after the installation of RF system, RFQ, MEBT (Medium Energy Beam Transport), diagnostic plate (D- Plate) and low-power beam dump (LPBD). The third phase, so called final phase, will be the integrated commissioning of the LIPAc up to 9 MeV with its SRF, HEBT (High Energy Beam Transport) and high-power beam dump. The duration of the project has been recently extended by about 3 years up to March, 2020 what allows the completion of the commissioning and operation of the whole accelerator at the nominal 1 MW beam power.

INSTALLATION FOR THE RFQ EXPERIMENT

The major components installed in the accelerator vault, injector, RFQ, MEBT, DP and LPBD, are shown in Figure 2. Their positions and beam axis were carefully aligned using the laser tracker. The RF power is transmitted with coaxial RF lines connecting the 8-RF modules and the corresponding 8 RF couplers of the RFQ. Such a simultaneous power injection using 8 ports is a first trial for the RFQ and enables the beam acceleration experiment up to 5 MeV/130 mA. The duty cycle is limited to 0.1% because of the heat removal capacity of LPBD and interceptive diagnostic tool. The CW beam operation can be carried out after the high power beam dump is installed.

RFQ

The LIPAc RFQ is the longest one in the world and has 9.8 m length in total. It was manufactured in INFN, Italy and assembled up to tripartition of the whole cavity. After combining them to a single cavity in a temporary position in

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61st ICFA ABDW on High-Intensity and High-Brightness Hadron Beams HB2018, Daejeon, Korea JACoW Publishing
ISBN: 978-3-95450-202-8 doi:10.18429/JACoW-HB2018-THP1WB01

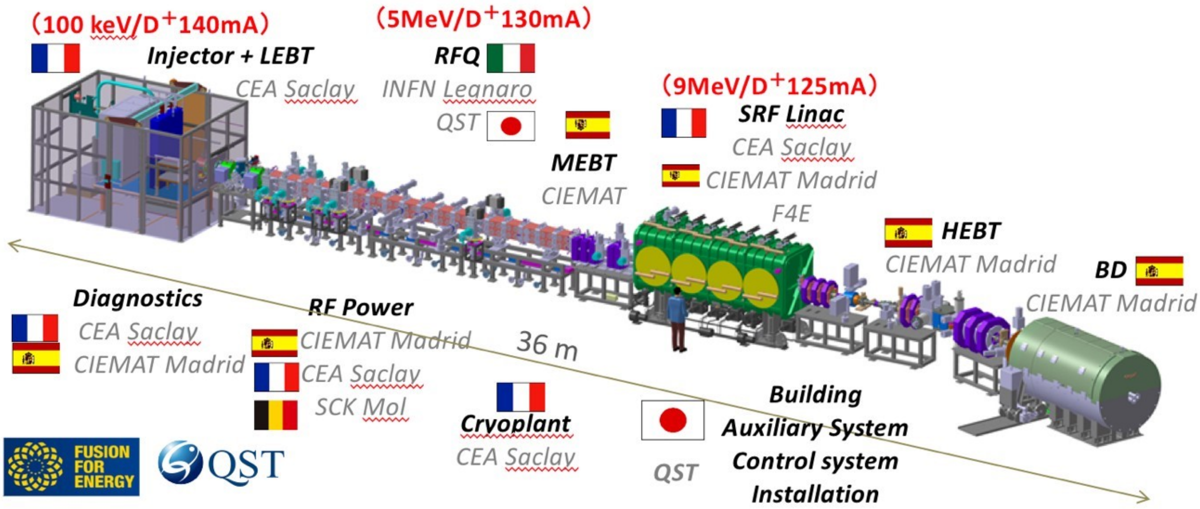

Figure 1: Configuration of LIPAc.

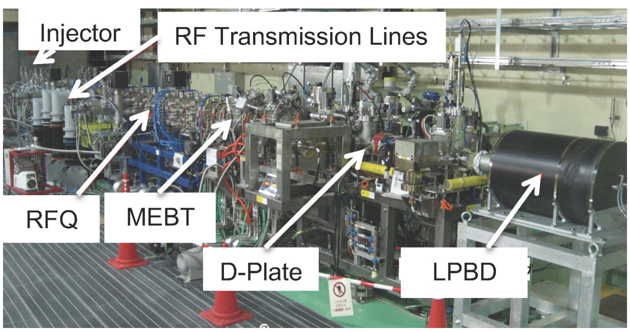

Figure 2: Accelerator components of IFMIF prototype accelerator.

the accelerator vault, the field and frequency tuning (the low power test) was conducted by means of the bead perturbation method as shown in Figure 3(a).

110 adjustable tuners were replaced with final tuners in 3 steps and all the test was completed 2016. After that, the vacuum equipment was assembled, and the baking of the cavity was done. The vacuum system check-out started, and finally the cryopumps were started [3]. The coaxial waveguides were connected and tested with control system [4] to RFQ in 2017 after the completion of the highpower test of the RF modules. All preparation for RFQ commissioning was completed in July 2017 as shown in Figure 3(b).

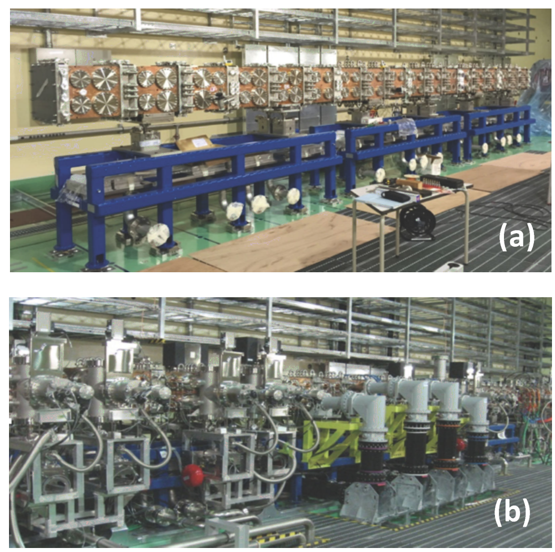

Figure 3: Progress of RFQ installation from (a) April 2016 to (b) June 2017.

RF SYSTEM

The RF power system as shown in Figure 4 consists of eight RF chains amplifying RF at 175 MHz up to 200 kW in CW or pulse waveform. The RF output power of individual chain is injected into the RFQ cavity through RF couplers respectively. Each RF chain synchronizes to the master RF chain through 10 MHz distributed from the White Rabbit to LLRF of the eight chains. The input power to the RFQ cavity (forward power) and reflected power from the cavity are detected from the directional coupler. Using a feedback system, the forward power from seven slave RF chains follow the reference RF power from the master RF chain. This function is essential to the RFQ linac since the RF power into the cavity must be balanced and in-phase [5].

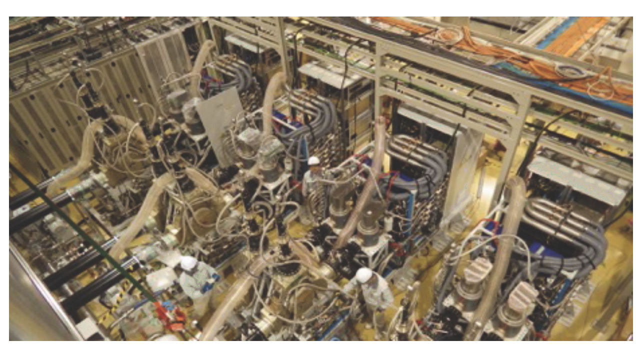

Figure 4: Installation of RF System.

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BEAM INJECTOR

The injector is composed of ECR ion source, 100kV beam extraction electrodes system with the secondary electrons repeller at the exit of extractor and Low Energy Beam Transport (LEBT) line. The alignment and the precision of the gap distance of the electrodes are very important to achieve the optimal beam performance. The low emittance beam can be obtained at high current beam through the careful tuning of the injector components. Figure 5 shows an example of the experimental results, extraction voltage dependence on the emittance of the 100 keV pulsed D+ beam at the various extracted beam current, 155 mA, 165 mA and 175 mA. These emittances were measured after the first solenoid of LEBT, however the emittances at the RFQ entrance point were almost same with them, which was confirmed through the series of injector beam commissioning campaigns in 2015 and 2016.

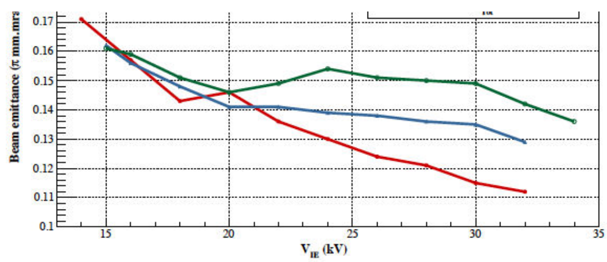

Figure 5: An example of injector beam performance: beam emittance vs. voltage of first extraction gap for D+ beam with energy 100 keV and various extracted beam current, 155, 165 and 175 mA (pulsed beam with 5% duty cycle and 2msec width).

RFQ COMMISSIONING

The commissioning of the individual RF chains was completed using the dummy load up to 200kW/CW in July 2017, and the RF conditioning has been started after the coaxial transmission lines were connected to the RFQ. A precise synchronization of the amplifiers phase and amplitude with an active feedback loop is realized by a fully-digitalized low level RF control unit combined with the "White Rabbit". The RF injection with 8 chains synchronization succeeded first time and the RF conditioning activity has been started in October 2017. One of the milestones of the RF conditioning was to obtain the maximum vane voltage in the RFQ cavity 132 kV, which corresponds approximately to the required target value to accelerate D+ beam as shown in Figure 6. This was realized relatively smooth RF conditioning by adopting an automatic rearming system of RF system when RF stops by multipactoring etc. The RFQ beam commissioning will be started firstly from June 2018 using the H+ beam to avoid the unnecessary activation and, after the enough H+ beam testing, the D+ beam acceleration up to 5 MeV will be implemented from the end of 2018.

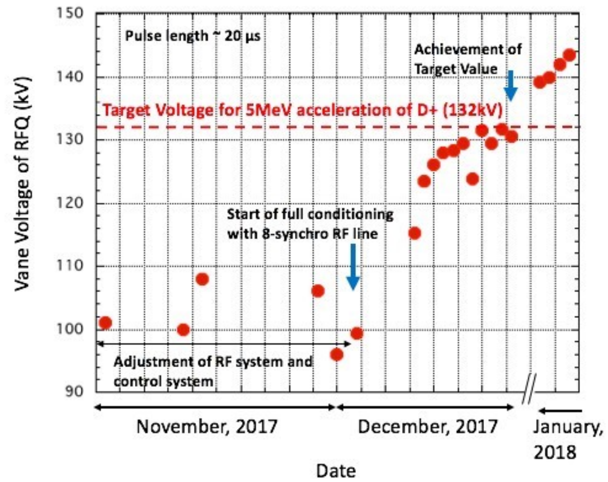

Figure 6: History of RF conditioning id RFQ up to target voltage for D+ acceleration.

ACKNOWLEDGMENTS

One of the authors (A. K.) would like to acknowledge Dr. Y. Shimosaki for supporting this presentation.

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